Final Report

Small Scale Polygons and the History of Ground Ice on Mars
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Progress has been made in these two key areas and is discussed below:

- Continued modeling the formation of thermal contraction polygons in martian permafrost, examining nominal polygon size and surface relief.

- Evaluation and publication of models of martian gully formation, specifically the potential melting of near-surface ground ice and the potential occurrence of shallow aquifers.

Polygons

Recent progress on polygon modeling has focused on the diameter and surface relief that we expect of thermal-contraction polygons in martian permafrost. With this in mind, we developed a finite-element model of thermal-contraction-crack behavior in permafrost in a martian climate. This model was generated from a finite element code by Jay Melosh (called TECTON) originally developed for terrestrial and planetary crustal-deformation studies [*Melosh and Raefsky 1980, 1981*]. TECTON allows stress and strain fields to be calculated given boundary conditions and rheologies. However, TECTON is not time-dependent in that rheologies and boundary conditions are set at initial values throughout the calculations. Additionally, TECTON has no prevision for thermal contraction. We adapted this model to martian permafrost by including time (and temperature) dependent rheologies, boundary conditions, and isotropic thermal-contraction, as well as several small adaptations to a martian environment. We tested our model extensively, including comparison to an analytic solution of pre-fracture stress (Figure 1) [*Mellon*, 1997].

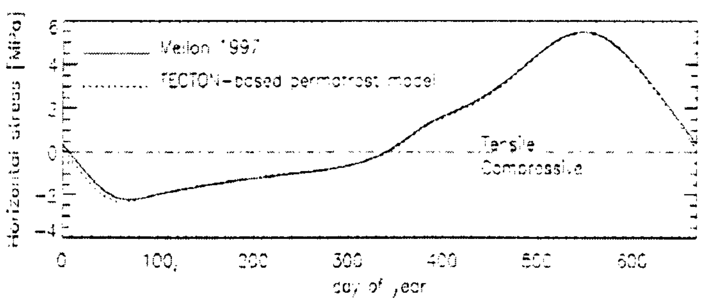

Figure 1: Pre-fracture stress comparison. Stresses are shown here at 50 cm depth, generated by thermal oscillations for the Viking 2 Lander site. No strain is allowed (i.e., no cracks are permitted) in the model. These two distinctly different modeling approaches compare quite well.

We used this TECTON-based permafrost model (together with a standard Mars thermal model [*Mellon et al.*, 2000]) to evaluate expected polygon size as a function of latitude, preliminarily using a pure-ice rheology. Figure 2 shows the maximum tensile stresses that occur in the permafrost versus polygon diameter. Figure 3 shows the peak central tensile stress versus initial polygon size. If the tensile stress at the center exceeds the tensile strength, a fracture will occur and the polygon will become subdivided. For example, in Figure 3 a tensile strength of about 1.6 MPa would cause a 20 m polygon to fracture and subdivide. Further, *Mellon* [1997] showed that peak tensile stresses will increase with latitude, due to low-temperature creep rates, resulting in smaller polygons at higher latitudes. In these initial calculations a pure-ice rheology was used; however, ice-cemented soil is more viscous and will result in higher stresses. Estimating polygon size from this process requires using the correct rheology compared with the tensile strength.

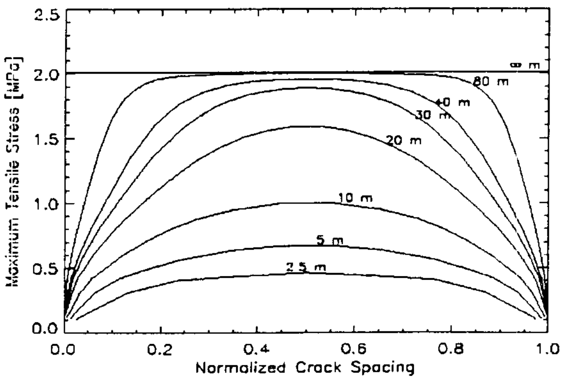

Figure 2. Peak seasonal tensile stress for polygons 2.5m to 80m dia. for 50°N and icy soil buried below 20cm of dry soil. Peak pre-fracture stress is ~2MPa.

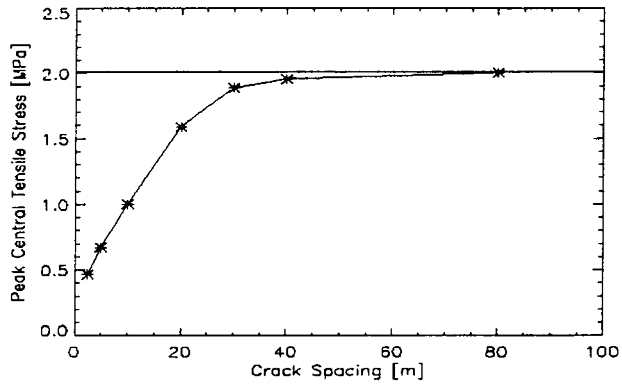

Figure 3. Peak central tensile stress from Figure 5. When stress exceeds strength, a fracture subdivide the polygon. The horizontal line indicates maximum pre-fracture stress.

The TECTON-based model also computes strains, which describe motion of the crack (opening and closing) and the net deformation of the surface (formation of observable relief). Although cracks only open a few millimeters during a season (in the model and in Earth permafrost), this allows us to evaluate infilling material (such as sand) and over many cycles the net effects on surface morphology that can be compared with observations.

Gullies

We recently published an analysis of two potential sources of water for forming the recent gullies [*Mellon and Phillips*, 2001]. In this work we first evaluated the potential for near-surface ground ice (in the top meter or so of soil) to melt under conditions of solar heating on sloped surfaces at high obliquity, utilizing both thermal and diffusion-based ground-ice-stability models; our results suggested that the ground ice will sublimate, and the ice table will recede to greater depths before the melting temperature can be reached. An exception can occur only for extremely salt-rich ice, depressing the freezing point.

We also evaluated the potential for a shallow aquifer to occur in the subsurface and for water from the aquifer to be expelled onto to the surface. In short, a shallow confined aquifer can be maintained at temperatures above melting by the occurrence of an overlying dry, low-thermal-conductivity soil (see Figure 7). Periodic partial freezing can be induced by normal orbital oscillations (Figure 7 isotherm "A" transitions to "B"), resulting in freezing pressure that will cause liquid water to erupt onto the surface. This model does not require high geothermal heat, hydrothermal activity, or unusual climate conditions.

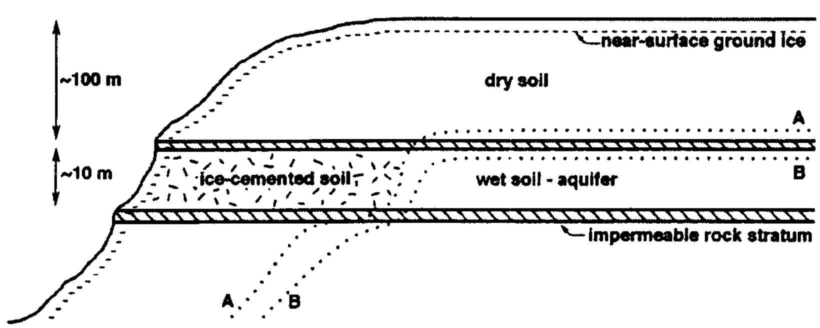

Figure 7: A model for the generation of liquid water and the formation of gullies on Mars. Obliquity-cycle induced freezing in a confined aquifer at shallow depth can generate enough pressure to fracture ice cemented soil [see *Mellon and Phillips*, 2001].

These two models provide several predictions that can be used to test the hypotheses (see also *Mellon and Phillips* [2001].

- Gully source depth. All else being equal, at higher latitudes the mean annual surface temperature will be lower than at lower latitudes. This will result in a greater depth to the base of the permafrost at higher latitudes (assuming the same heat flow and soil conductivity). Thus, in the shallow aquifer model, the depth from which water originates from the subsurface will increase with latitude. On the other hand, near-surface ground-ice melt will occur at all slope elevations regardless of latitude, as there is no thermal difference in solar heating from the crest of the slope to the base.

- Gully population density. In the shallow aquifer model, the partial freezing that would be induced by orbital oscillations is minimal at a narrow band in the mid latitudes (near 50°), due to the nature of the heating and cooling as a function of the martian orbit. Therefore, gullies would occur less frequently at this latitude. Near-surface ground-ice melt would occur at all latitudes, as the temperature that occurs at the depth of the ice table is actually independent of latitude.

- Slope orientation. *Malin and Edgett* [2000] report that gullies occur more frequently on poleward facing slopes. But they do not report if there is a latitudinal dependence of this correlation. The shallow aquifer model requires the long-term stability of near-surface ground ice to confine the aquifer along the slope surface. Equatorward facing slopes are warmer and at lower latitudes near-surface ground ice would be unstable, compared with poleward facing slopes at the same low latitude. Therefore, at lower latitudes we would expect gullies preferentially on poleward facing slopes. At high latitudes near-surface ground ice would be stable on all slope orientations and no dependence should be observed. Melting of near-surface ground ice would be entirely independent of slope orientation, as the temperature at the ice table is independent of slope [*Mellon and Phillips*, 2001].

References:

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